

## HYBRID NETWORKING: EVOLUTION TOWARD COMBINED IP AND DYNAMIC CIRCUIT SERVICES



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There is a wide consensus among service providers, operators, equipment vendors, and academics that the next decade will see highly evolving Internet and network transport architectures. Both circuit and packet switching technologies will be used in hybrid networks that will offer both IP packet and dynamic circuit services. A variety of switching technologies, such as multiprotocol label switching (MPLS), carrier Ethernet based switching, and wavelength-division multiplexed (WDM) optical switching, will be used to offer dynamic (virtual) circuit services, while IP routers will continue to be used for IP packet services. Integrated systems that offer both IP-layer forwarding and MPLS switching, or other combinations, will be used in these hybrid networks.

Hybrid network services will no doubt change the ways in which future networks are designed and operated. With the emergence of 100 Gb/s Ethernet, the key question is to determine the optimal level of coordination and integration between packet- and circuit-switched technologies and services. This question will become increasingly important not only for the Internet and telecommunications service providers, but also for data center interconnects, cloud computing systems, and green networks.

Under this feature topic, we are pleased to present five articles that cover recent advances in hybrid networking, and discuss challenges and opportunities for emerging networks that offer both IP packet and dynamic circuit services. The first three articles address ongoing research and engineering efforts in operating a hybrid energy sciences network for the U.S. Department of Energy, where the authors share their experiences, present their work on new architectural frameworks and provisioning tools, and describe real-world challenges. The next two articles are on combined IP/optical network restoration and programmable hybrid router design.

The first article, titled “Hybrid Networks: Lessons Learned and Future Challenges Based on ESnet4 Experience,” shares the experiences of operating a hybrid infrastructure consisting of separate IP-routed and dynamic circuit networks. It also discusses open research problems, the potential value of hybrid networks in cloud computing and data center interconnects, and the use of optics within computer chips of exascale supercomputers. The second article, “Multilayer Networks: An Architecture Framework,” presents an architecture framework for the control and management of hybrid networks and associated network services. With service requirements driven by increasingly stringent user needs and pressure to reduce

operational costs, such frameworks will play an important role in the future Internet. The third article, “Advance Reservation Frameworks for Wavelength-Routed WDM Networks,” offers readers a survey of different networks and frameworks that support advance reservation of bandwidth.

The fourth article, titled “Shared Backup Router Resources: Realizing Virtualized Network Resilience,” presents and analyzes the use of dual homing with shared backup router resources in hybrid networks. Finally, “A Standard-Based Approach to Programmable Hybrid Networks” describes a software prototype of a hybrid programmable node in which optical crossconnect capability is added to the Click (software router) package. The impact of adding and removing circuits dynamically on IP-routed flows that share the same links is measured with experiments on a testbed consisting of these programmable hybrid nodes.

We hope the readers find the articles in this feature topic on hybrid networking of interest. On behalf of the editorial board, we would like to thank all the authors who submitted papers, and all the reviewers for their diligent work.

### BIOGRAPHIES

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